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ART. XXVII.—*On Iron*, by HENRY WILKINSON, Esq., M.R.A.S.

Read 16th February, 1839.

IRON has been applied to numerous useful purposes, by every civilized nation, for thousands of years ; but never has it been so extensively employed as at the present period. We have iron roads and iron carriages ; the "wooden walls of old England" will probably be made of iron in another century ; numerous steam-boats are already constructed of that material ; the cushions of our chairs are stuffed with iron in place of horsehair ; and not only our bedsteads but even our feather beds (to use an Hibernicism) are made of iron.

These are, however, merely mechanical applications of this important metal ; but when we are told of living animals whose bodies are composed almost wholly of iron, encased in flint, and that these animals feed on plants, have the power of motion, and can live in muriatic acid, it may at first excite a smile of incredulity ; nevertheless Professor Ehrenberg has discovered, that the bog-iron ore, from which the beautiful Berlin castings are made, originates from an animalcule that once had life, the whole mass being composed of the bodies of myriads of these animals ; and that the Tripoli or polishing powder so extensively used in the arts, and in Berlin, to form the casting-moulds in the iron founderies, is entirely composed of the shells of similar animalculæ, capable of bearing a red heat without destroying their outer coating or shell. What is still more satisfactory and more extraordinary, these animalculæ do not form an extinct or doubtful species, but actually exist in abundance in the waters and ditches near Berlin ; and not only abroad, but so near home as to have been recently met with at Hampstead and Highgate. These are facts calculated not only to astonish, but to establish our extreme ignorance of the laws and operations of nature ; and having been demonstrated beyond the possibility of doubt, it is in the power of every one to satisfy himself of the truth of Professor Ehrenberg's statement*. Dr. Faraday has shown that iron will remain for months in *strong* nitric acid, without the slightest action taking place, although in diluted or weaker acid it is instantly attacked with violence : he has proved that when chemical action ceases, electrical action ceases also, and *vice versa* ; and has also shown that

* Vide Paper read by Professor Ehrenberg at the Royal Academy of Sciences at Berlin, July 7, 1830, and *Scientific Memoirs*, vol. i. part 3.

platinum and carbon act as protectors to iron under such circumstances. These curious facts sufficiently attest the importance of a subject which appears hitherto to have eluded the grasp of every philosopher. Every artisan who is in the habit of working this metal imagines he understands its properties perfectly, and so he does as far as regards the mere adaptation of it to his own immediate purposes ; but to the chemist and philosopher it presents so many anomalies, that iron at the present moment occupies the attention of the scientific men of every country, as a problem they have hitherto been unable to solve. Its chemical and electrical properties are at variance with all preconceived ideas, and it appears to possess some extraordinary relation to other bodies which, whenever it may be satisfactorily explained, will open an extensive field of scientific inquiry, and prepare the way for the most important discoveries. It must therefore be universally acknowledged that iron is the most valuable and most important metal with which we are acquainted.

Platinum, gold, silver, copper, and most metals in ordinary use, appear, when purified, to be nearly the same in quality from whatever part of the world they may be obtained ; but iron varies so much, according to the nature of the ore and method of reduction, that hardly two specimens of iron from different countries, or even from different parts of the same kingdom, are alike in those properties which characterize the metals, such as tenacity, ductility, and fusibility. The consideration of these facts having occupied much of my time, and caused me to make many experiments, I am inclined to offer some remarks, which, if not new, may possibly lead those who have more extensive means and opportunities, to pursue the subject with greater advantage than myself. Any attempt to elucidate this interesting subject, even theoretically, must be acceptable, especially if new or forgotten facts can be adduced to bear upon the point in question.

Of all the agents which it has pleased the Creator to employ in the grand system of the universe, there is none which appears to exert so much influence as electricity, taken in its most extended meaning. Gravitation and attraction, the laws by which bodies are *drawn* together, and cohesion, that property by which they are *held* together, have all been referred to electrical causes ; and the various branches of science designated Electricity, Galvanism or Voltaism, and Magnetism, which were formerly considered distinct from each other, and governed by different laws, have now been demonstrated to be merely modifications of that universal electrical action by which we are continually surrounded, and of which every body in

nature appears to partake, but which action is only rendered evident to our senses when the equilibrium is destroyed by some exciting cause. Now, iron is a metal well known to exhibit in the most striking manner the phenomena of electricity in that form called magnetism; and it has always appeared to me, *that the different states of iron and steel depend on electrical causes modified by the action of carbon and oxygen.* In order more clearly to comprehend this subject, I must briefly, and therefore imperfectly, explain the usual method of manufacturing iron in Europe. The ore is first broken up and roasted, in order to drive off the sulphur and other volatile ingredients; it is then mixed with a certain quantity of limestone and charcoal, and the whole thrown into a furnace heated with coke, or charcoal. The carbon combines with the oxygen of the iron, (an aluminous iron ore, or protoxide of iron, being most usual,) and escapes in the form of carbonic acid gas, while the clay unites with the lime, and forms a kind of fluid glass, or scoria, which floats on the surface, protecting the iron from the action of the atmosphere, and acting as a flux; the iron sinks to the bottom, from whence, when in perfect fusion, it is allowed to flow into channels or moulds prepared for its reception, and in this state is called *cast-iron*, which is iron combined with various doses of carbon and oxygen and other impurities, constituting the varieties called *white*, *gray*, and *black*, according to the quantity of carbon absorbed. When broken, the fracture is coarse and granular, depending on the size of the crystals, and in this state I conceive the crystalline arrangement to be greatly influenced by electrical causes. In order to convert cast-iron into malleable or pure iron, the oxygen and carbon must be driven off, which is now effected by a process called *puddling*, invented about fifty years ago by Cort; this operation consists in exposing the iron to a high temperature in a reverberatory furnace, the flame of which plays upon the metal: the workman keeps stirring it about until it assumes a pasty* consistency; but previous to this the whole mass, at a certain temperature, disintegrates, falling to pieces like sand, the particles having lost all cohesive or electrical attraction: the flame being then urged on, the temperature rises, and adhesion again takes place; it is then removed and beaten under a hammer of several tons weight, worked by steam power; this condenses the metal and drives out the impurities; afterwards it is again heated, and drawn out into bars either by *tilting* or *rolling*. During the process of *puddling*, the mass heaves and swells, giving out jets of flame, evidently caused by the emission of inflammable gas. The metal

* Technically called "*coming into nature.*"

thus prepared is malleable iron ; it has lost all its former brittleness, and has no longer the granular structure of cast-iron. It is evident that, by continual agitation the particles are prevented from assuming any regular or natural arrangement : hammering and elongation convert the crystals into fibres, and the tenacity is increased in proportion to the decrease of granular or crystalline structure. In this operation, art interferes with the laws of nature ; and malleable iron thus prepared, is iron deprived of its carbon and oxygen, depending for its qualities on a variety of circumstances, such as a minute alloy with the metallic bases of the earths or with other metals and impurities ; the strength of its fibres being influenced by the original size of the crystals of which these fibres are composed, in the same manner as the strength of a rope depends, first, on the quality of the hemp or flax, and secondly, on the comparative fineness or coarseness of the individual threads of which it is formed. In malleable or pure iron, therefore, the crystalline arrangement is destroyed ; in this state it is incapable of being rendered permanently magnetic, or of receiving any increase of hardness by sudden changes from heat to cold, as by making red-hot and plunging into water ; but if we simply stratify bars of iron with charcoal, and expose them to a proper temperature in a furnace for a given time, the *iron* becomes converted into *steel* by the absorption of a minute portion of carbon, and its properties are completely altered ; it will now permanently retain magnetism, and will become hard enough to scratch glass when made red-hot and plunged into cold water ; it has also completely changed its appearance on fracture, which could only be effected by the particles being removed far enough asunder by the action of heat to enable them to arrange themselves according to their natural laws at that temperature, which laws appear to be governed by electrical action.

Steel, however, when first prepared as described, is only suitable for common purposes, and is called *blistered steel*, from its appearance. In order to render it suitable for finer purposes, the blistered steel is either *fagotted* (i. e. packed together) and then welded, to form *German* or *shear steel* ; or, it is broken into small pieces and fused in a crucible with carbon, in order to convert it into the finest kind called *cast steel*. In the latter process, the particles being in a state of fusion, and having a perfect freedom of motion, are at liberty to arrange themselves according to natural or electrical laws modified by carbon only : the fracture then assumes a fine granular appearance, caused by the smallness and regularity of the crystals. The difference between the European and Oriental

methods of conversion, consists in the greater simplicity of the process adopted by the latter. *Wootz*, or Indian steel, is prepared by breaking up the iron ore and throwing it into a charcoal furnace, urged by bellows worked by men, from whence the iron is at once obtained in a malleable state, and being cut into pieces of about one pound in weight, is converted into steel by putting it into a crucible with the dried branches and green leaves of various shrubs. The natives of India consider that the different kinds of wood employed in the first reduction of the ore, as well as in the subsequent conversion of the iron into steel, have a decided effect in producing different qualities of iron and steel. The *wootz*, or steel, being allowed to cool in the crucible; the particles have sufficient time to arrange themselves and form crystals: hence arise those beautiful combinations which, when forged into sword blades, produce the Damascus figure, or "*Jowher*," as I have more fully explained in my paper on this subject, published in the *Journal of the Royal Asiatic Society* in 1837. Good steel, however, from whatever source obtained, possesses the property of becoming extremely hard by being heated to a bright cherry red and then plunged into water.

The reason appears to be that by the action of heat the particles arrange themselves according to the temperature, and being suddenly fixed in that state by cooling, are held in a state of tension similar to glass when unannealed, and like it also are extremely brittle; the particles when cold, being by the sudden change fixed in the same position as they were while red hot. This extreme hardness renders the steel unfit for a variety of purposes, it therefore requires to be tempered, or *taken down*, in order to make it available for cutting instruments of every description and for springs; this operation consists in again gradually raising the temperature of the steel until it assumes various shades of colour caused by the thickness of the oxide formed on the surface, which should be previously polished; the colours produced in succession are, first, a very pale yellow, which comes on at a temperature of 430° to 450° ; a straw colour at 460° , a brownish metallic yellow at 500° , then brown, red, and purple to 580° , when it begins to assume a fine deep blue, like watch springs. If the heat be continued until quite red hot and the steel be allowed to cool slowly, it will become as soft as it was before it was hardened. This takes place in consequence of the particles endeavouring to regain the position which they occupied previous to hardening. At every increment of heat, additional freedom of motion is communicated to the particles by separating them further asunder, which adapts the steel to the peculiar purposes for which it

may be destined ; but it does not wholly recover its natural state until rendered as soft as possible, by the gradual process of slow cooling. By what power is this continual motion of the particles effected? I conceive it to be *the power of electrical action which varies with every change of temperature.* Heat merely separating the particles far enough asunder to admit of motion taking place ; and there is no doubt, I think, that every change of temperature in the atmosphere produces corresponding changes on the particles of all matter, although insufficient to be evident to our senses.

Theories, however plausible, are of little use, unless they can be applied to some practical advantage, and the object I have long had in view, is to test this theory by experiments, which want of time has hitherto prevented. I consider, that when steel is in a state of perfect fusion, it is highly probable that its quality might be materially influenced by causing it to be acted upon by artificial electrical currents, allowing it to cool and become solid while under that influence. Experiment alone can determine whether this opinion be correct or otherwise ; and if correct, whether beneficial or injurious.

I hope to receive a variety of specimens from India, with answers to a series of questions I proposed some time since, through the medium of this Society, but which have hitherto been unavoidably delayed. When they arrive, I shall feel great pleasure in communicating the result of my inquiries to this Society.

The accounts already published and in MS. respecting the methods of preparing iron and steel in India, are already sufficient for every purpose of general information, but in order to investigate the subject more closely, I am desirous of obtaining specimens from various provinces of India, arranged in the following order, together with any local information suggested by circumstances, and I am authorized by the Royal Asiatic Society to state, that they will feel obliged to any gentleman whose leisure and opportunity may enable him to forward specimens and replies to their Secretary in London.

1st.—Specimens of the ore as taken from the mine, specifying the locality and whether washed, or roasted before being put into the furnace.

2nd.—Portions of the iron as taken from the furnace ; a few pounds in weight.

3rd.—One or two crucibles with the iron, wood, and leaves, just as prepared by the native workmen, to be placed in the furnace for conversion into wootz, or steel.

4th.—One or two crucibles, containing the steel, as taken from the furnace after conversion, without being broken or opened

5th.—Several specimens of the wootz, or steel, made at the same time, just as taken from the crucibles, especially those made nearest to Cutch, and usually in flat cakes, about one inch thick, and three or four inches in diameter. Also, whether the natives are aware, or have any means of ascertaining by external appearances, whether the cakes are full of "*jowher*" or figure, so as to produce good Damascus sword-blades.

6th.—Description of the native mode of working the identical quality of steel sent as specimens, with any implements manufactured by them from the same.

7th.—Specimens and description of the wood employed for charcoal in the furnaces.

8th.—Specimens and description of the wood used in the crucibles, and also of the green leaves employed in the conversion of the iron into steel, with the botanical and native names when known.

Note.—Some specimens of wootz, or steel, examined by me, and said to come from *Cutch*, were full of the "*jowher*" or watering, peculiar to Damascus sword-blades, and when forged out, showed most distinctly the crystalline arrangement.
